AN OBJECTIVE METHOD OF FORECASTING RAIN IN CENTRAL CALIFORNIA DURING THE RAISIN-DRYING SEASON

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THE PROBLEM

Forecasting rain for raisin-drying areas in the San Joaquin Valley of central California long has been a problem of major economic importance [1]. The raisin crop grown and processed in this area is valued at millions of dollars annually.[1] During the late summer and early fall season, when the raisin grapes are dried in the open, unexpected rainfall amounts in excess of a few hundredths of an inch will adversely affect the exposed grapes. Raisin grapes are dried either on trays or on paper, and when rain threatens, growers stack the trays or roll the papers to protect the drying fruit. The expense involved in carrying out these protective measures is such that they cannot be undertaken unless a loss to the crop is threatened.

The vital importance of forecasting rain for these areas led to the investigation which is reported in this paper. Its objective was to determine the value of a number of meterological variables commonly used in preparing precipitation forecasts for the area during this season and to discover, if possible, combinations of the variables which have definite forecasting possibilities. The approach to a rain forecasting problem developed by Brier [2] was used to advantage.

GENERAL ASPECTS

In this investigation, several general aspects of the problem were considered before the development of an objective procedure was undertaken. They included (a) topographic and climatic influences which make forecasting rain for the San Joaquin Valley a unique problem; (b) rainfall frequency at Fresno, a knowledge of which is helpful in establishing the most critical periods of the season; (c) choice of forecast periods which must be adjusted to the growers' needs and to the observation times; and (d) data which were available for use in the study.

TOPOGRAPHIC AND CLIMATIC INFLUENCES

Forecasting rainfall in the Valley is a unique problem since that area is in a rain shadow for storms approaching from any direction except the north. Directly to the east are the Sierra Nevada Mountains; to the south, the Tehachapis; and to the west, the coast range. (See fig. 1.) In addition, storms approaching from the north must first

pass over the mountains in the northern portion of the State, and they are subsequently affected by a disrupting influence in passing southward through the Great Interior Valley comprised of the Sacramento and San Joaquin Valleys. Thus, rainfall may occur in heavy amounts in surrounding mountains, mainly in the high Sierras, with little or none reaching the floor of the Valley.

Because of the existence of the rain shadow in this forecast area, rainfall due to frontal action is of negligible importance unless associated with convergence at intermediate levels aloft. Except for areas in the foothills—which are almost wholly out of the raisin-drying region—rainfall

FIGURE 1.—Relief map of California showing rainfall stations in the San Joaquin Valley used in this study.

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[1] The value of the 1946 raisin crop has been estimated at about 55 million dollars, with almost the entire crop exposed to the weather at the peak of the drying season. Although no loss occurred in 1946, losses to the drying crop from unexpected heavy rainfall have been as high as 20 percent in the past, with a loss of almost 100 percent possible.

due to orographic lifting is also negligible. In seeking meteorological indices capable of producing worthwhile results in forecasting, it was therefore necessary to place the main emphasis on variables other than those involving frontal and orographic effects. In general, it was necessary to get some indication of the convergence in low and intermediate levels, together with temperature and moisture measurements.

Complications are introduced into the forecast problem due to the proximity of the forecast area to the ocean, to the marine climate in coastal sections, and to the desert climate east of the Sierras and to the south of the Tehachapis. Although the Valley is protected from a direct marine influence by the coastal range of mountains, modified marine air is continually feeding in through the break in the coast range in the vicinity of San Francisco Bay and to a lesser extent from the west directly over the coast range. Because of the presence of the modified marine air in the lower levels of the atmosphere, surface moisture is not representative of the moisture through a deep layer.

An additional effect during the season under consideration is the marked distortion in the low-level pressure field which results mainly from two well-known factors: (a) the heat low of the southwest, generally centered over the Colorado River Valley, together with the commonly associated thermal trough which extends to the north-northwest through the interior of central and northern California, occasionally reaching as far north as western Oregon and Washington; (b) the persistent marine inversion with the underlying layer of cool marine air along the coast. Sea level pressures beneath a well-marked surface inversion may exist several millibars higher than in adjacent areas unaffected by this cool air. With the thermal low and the marine inversion well developed, surface data over the Southwestern States become nonrepresentative of developments in the upper circulation which may become sufficiently intense to produce rain. As the season progresses, however, the continental upper anticyclone becomes less predominant, and surface troughs moving into the Pacific Northwest tend to weaken the coastal inversion. Under these conditions the surface data are important meteorological indices.

RAINFALL FREQUENCY AT FRESNO

To determine the critical periods of the season, a study was made of the frequency of occurrence of measurable precipitation at Fresno, by 5-day periods for the months of September and October. The summary shown in figure 2 indicates that the rainfall occurrence by 5-day periods is about 5 percent at Fresno before September 20, but immediately thereafter it increases to about 35 percent. This sudden increase during the last decade of September may be due to a weakening and slight southward movement of the upper continental anticyclone, which allows frontal systems to encroach farther and farther southward. At the same time there may be an increase in the number of tropical storms moving northward toward the area. A decrease in heavier rains during the second decade of October is believed to be a result of the ending of the tropical storm season, although sufficient data are not available to establish this fact.

CHOICE OF FORECAST PERIODS

Forecast periods are determined by the requirements of the growers and the times that weather observations become available. In order to complete protective measures in case of a developing rain situation, growers re-
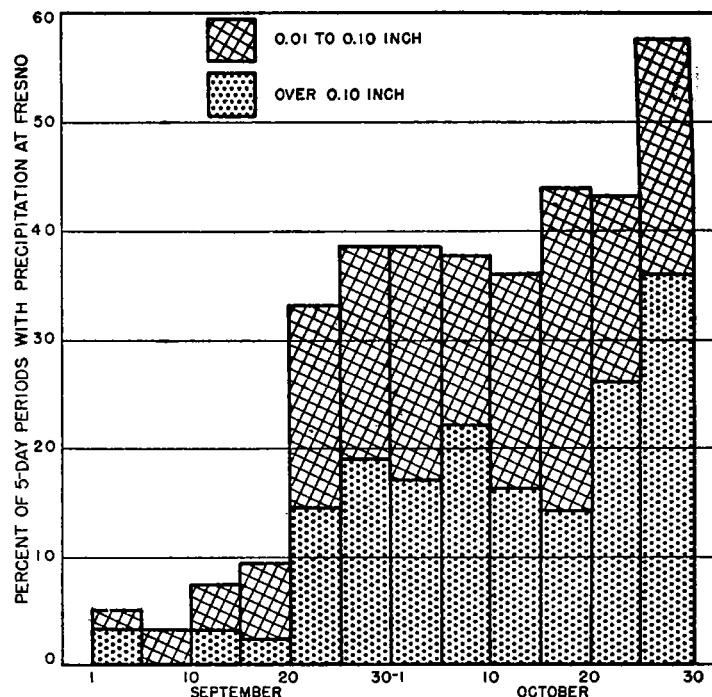

FIGURE 2.—Graph showing frequency of occurrence of measurable precipitation at Fresno by 5-day periods for the months of September and October for the period 1887 through 1945.

quire a minimum of 6 hours of daylight prior to the onset of rain. A forecast made at 6 a. m., P. S. T., for instance, gives them sufficient time if the rain is not to begin until afternoon. For a rain which begins during the morning hours, however, a satisfactory forecast must be issued by noon of the preceding day in order to give warning 6 hours before dark.

On the Pacific coast, upper-air data become available generally at about the 10:30 a. m. and 10:30 p. m., P. S. T., synoptic map observation times. Since current information for the upper air is essential in preparing the forecast, these times were chosen for making twice-daily forecasts. At these times available information includes 8 a. m. or 8 p. m. pilot balloon data; 7 a. m. or 7 p. m. raob data; and 10:30 a. m. or 10:30 p. m. surface observations. Since a forecast of rain within 6 hours of the time of issuance of the forecast is of little value, the period to be covered by the forecasts was chosen as 6 to 24 hours after map time. It was found that this time could be extended by requesting special telegraphic reports from raob stations, whereby necessary information could be obtained as early as 8:30 a. m. By using current surface data also (7:30 a. m., 3-hourly reports) the forecast could be prepared approximately 2 hours earlier, thus in effect changing the forecast period to 8 to 26 hours.

DATA AVAILABLE FOR STUDY

Fresno is located near the center of the raisin-drying area, and rainfall amounts occurring there and at five surrounding stations—namely, Madera, Clovis, Visalia, Lindsay, and Hanford—were used in determining the rainfall parameter. (Locations of stations are shown in fig. 1.) Of the six stations, only Fresno had an accurate record of the times of beginning and ending of precipitation. For this reason, the average total amount occurring at the six stations was adjusted as to time of occurrence in proportion to times of occurrence at Fresno.

The most critical period in the fruit-drying season, approximately from September 1 to October 15, was

chosen for the study. Prior to 1942 upper-air data were sparse, and for this reason it was impossible to extend the study back beyond that year. Satisfactory data, which were available for the years 1942 through 1947, inclusive, were used in the completed study. Because of this short record, a statistical treatment of the results of the study suffers from lack of data, a deficiency which is further emphasized by the small climatological expectation of occurrence of rain during the season under consideration. Notwithstanding these factors, the urgency of the need for a solution to this forecasting problem was such that an intensive study was deemed advisable with the available data.

CLASSIFICATION OF SYNOPTIC MAPS

The first step in developing an objective forecasting method within the limits imposed by the general aspects already considered was to devise a procedure for classifying synoptic maps on a basis determined by a study of rainfall situations.

RAIN-PRODUCING SITUATIONS

Synoptic situations which result in the occurrence of important amounts of precipitation generally fall into four different types, each of which has a characteristic upper-air distribution of pressure and temperature and a somewhat less characteristic distribution of surface data, depending upon the individual type. The four types and the characterizing features are:

Type 1.—Upper cold low over or in vicinity of area. (Not necessarily reflected clearly in surface pressures.)

Type 2.—Wave formation on nearly stationary front off coast.

Type 3.—Development of plateau low over central Nevada, generally preceded by the movement of a weak front into area.

Type 4.—Movement of decadent tropical storm toward or into area.

Mean maps for 10,000 feet during the summer and early fall show the upper-level continental anticyclone to be the dominant feature in the circulation over the western United States [3]. A fairly broad trough off the west coast separates the high-level continental anticyclone from the anticyclonic circulation above the Pacific high. Under conditions which are not fully known, but which evidently depend in part upon the wave length in the upper-air flow [4], an upper cold low will move into or form in the area off the central and southern California coast, with resulting precipitation in inland areas. This type of development results in the rain-producing situation listed under type 1. Under other conditions, the trough between the two anticyclones intensifies and moves toward the coast, allowing frontal systems to approach the area from a westerly direction, thus leading to either type 2 or type 3 of the rain-producing situations. Type 4 occurs generally with the upper continental anticyclone well developed, with southerly winds aloft favoring the movement toward the area of decadent tropical storms. As disturbances move inland with the accompanying upper trough, the winds aloft shift into a northerly direction with a rapid decrease in the probability of rain.

CLASSES OF UPPER-AIR FLOW

An inspection of the upper-air charts for the period of study shows that in general the type of rain situation which may develop depends upon the position of the forecast area with respect to the upper-air flow. Three unique classes were distinguished on the basis of the three possible positions of the area, outlined in the schematic diagram of the circulation of the 700-millibar level shown in figure 3 (a). Class I circulation may result in types 1 and 4 rain-producing situations, while class II circulation develops types 2 and 3 situations. During the existence of a class I or class III circulation, a rapid change into a class II may occur with the movement into the Pacific Northwest of a deep low pressure system. The approach of this system is first noted in the upper air by a rapid fall in the 700-millibar level at Seattle.

A study of class II charts indicated the necessity of dividing this class into two subclasses characterized by contrasting meteorological developments. With the weakening of the upper continental anticyclone toward the end of September, surges of cold air moving southward over the northeast Pacific occasionally reach south of 35° N. latitude. If the cold air moves inland into the Pacific Northwest, with pressures relatively high over the northeast Pacific, cyclogenesis usually occurs over the plateau, with lowest surface pressure over central Nevada and with the axis of the low sloping toward the northwest. However, if the main portion of the cold air remains off the coast, a broad, relatively intense trough aloft will exist from the Gulf of Alaska southward to about 30° N. latitude. with minor anticyclonic circulation above the eastern Pacific high. On the basis of these two types of upper-air flow, the cases falling into class II were subdivided into classes II$_A$ and II$_B$, respectively. Upper-air flow patterns typical of these subclasses are shown in figure 11.

OBJECTIVE METHOD OF CLASSIFICATION

Following the subjective consideration of upper-air flow patterns just described, an attempt was made to develop a method whereby the classification of each situation might be designated in an objective manner based on pertinent data. Classes I and II are characterized by the existence on or near the coast of a marked trough in the upper air [indicated in figure 3 (a)]. The center of activity is to the south in a class I rain situation and to the north during a class II development. With the transition to class III, the trough aloft moves inland. The three classes were determined objectively by employing the heights of the 700-millibar level at Medford (MF), Oakland (OA), Ely (PEV), and San Diego (SQ), and the 24-hour change in height of the 700-millibar level at Seattle (SA). The position of the upper trough was defined objectively by comparing the average height at Oakland and Medford with that at Ely to distinguish between the first two and the third classes. Thus, with the average height at Oakland and Medford equal to or less than the height at Ely, the situation falls into class I or class II, while an average height at the two stations greater than that at Ely indicates class III—with the exception that a 24-hour fall of 250 feet or more in the 700-millibar level at Seattle always results in a class II designation. Classes I and II were distinguished by comparing the heights at San Diego and Ely. With the height at San Diego equal to or less than that at Ely, the situation falls into class I, with the exception noted above. With the height at San Diego greater than at Ely, the situation is placed in class II. Class II was further divided into its two subclasses, depending on the surface pressure at 45° N. latitude, and 140° W. longitude. An outline of this objective classification procedure is given in the diagram of figure 3 (b).
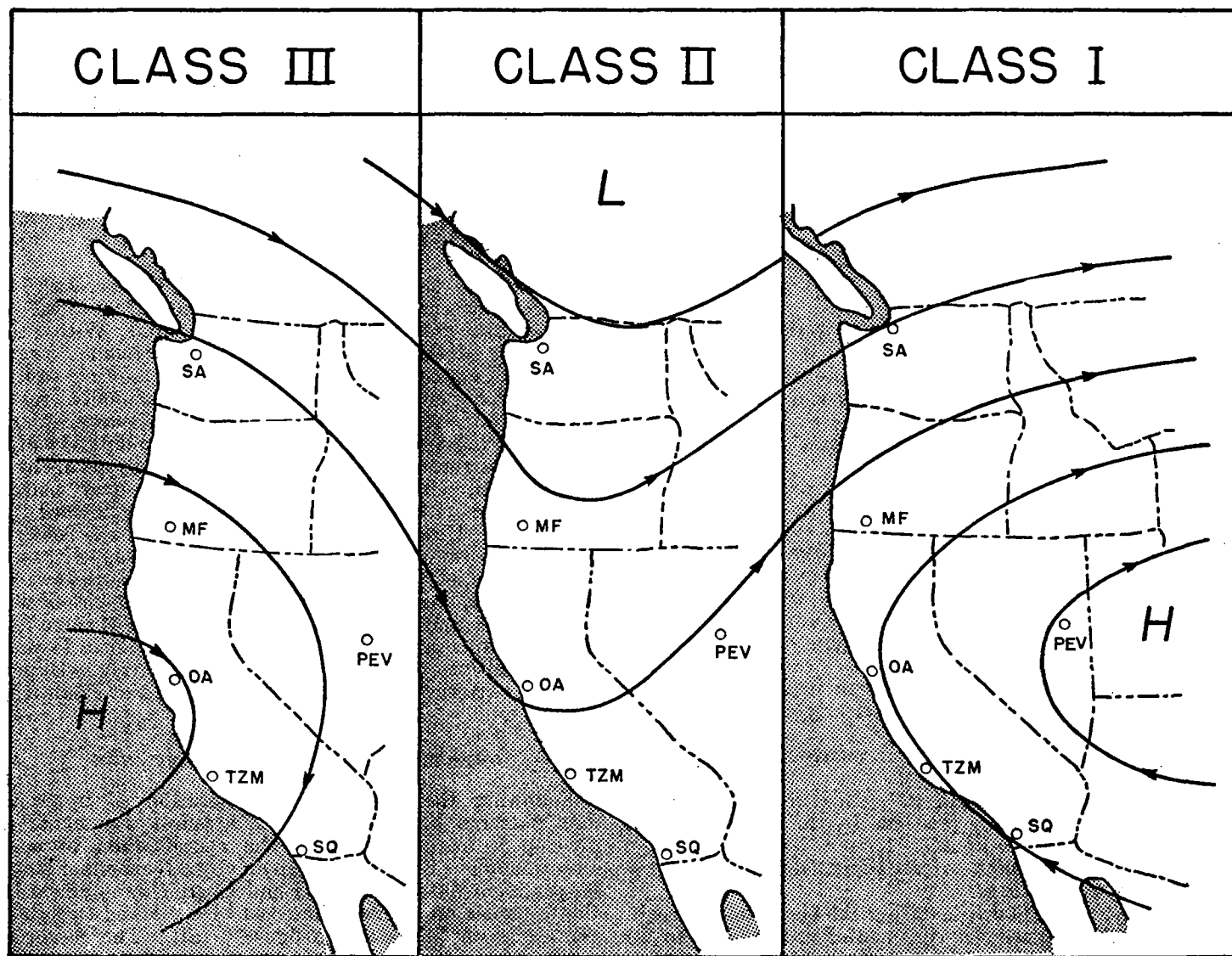
FIGURE 3 (a).—Schematic diagrams showing three possible positions of forecast area with respect to circulation at the 700-millibar level which form the basis of the three map classifications.

CHOICE AND COMBINATION OF METEOROLOGICAL VARIABLES

Following the classification of the synoptic maps, the next step in developing an objective forecasting method was to choose and combine for each class the meteorological variables indicative of rainfall. The general method of choice and combination of the variables is described below preceding the discussion of the procedure by classes.

During an exhaustive search for variables showing a definite correlation to the occurrence of rain in the area during the forecast period, a large number were tried, most of which showed a definite forecasting value. With the possible choice of variables and combinations of variables almost limitless, the number to be considered worthwhile was narrowed down by applying the knowledge of experienced forecasters. Due to the apparent interdependency of many of the variables involved in the analysis of any weather situation, the number retained to form the final forecasting procedure was kept to a minimum. Variables thus chosen were those which gave, first, the best stratification of rain and no-rain cases on a scatter diagram, and secondly, a distribution or additional

stratification showing a marked tendency for heavier amounts of rainfall to occur within the area of greatest probability on the diagram. Further, they had to indicate qualitative or quantitative improvement in the final forecasting procedure.

The procedure used in preparing charts showing lines of equal probability is similar to that described by Brier [2]. The combination of two variables was accomplished by plotting values of one variable as abscissas and corresponding values of the other as ordinates on a scattergram. Each point was labeled with the amount of precipitation occurring during the forecast period, 6 to 24 hours after map time. Although precipitation amounts which are not greater than 0.10 inch in any portion of the area do not require that protective measures be taken, the occurrence of even a trace of rain indicates an exceptional situation, inasmuch as it occurs during the dry season. Furthermore, a trace during a forecast period may indicate heavier amounts to follow. For these reasons, any amount of rainfall was identified as a rain occurrence for the purposes of drawing isopleths. When there is a uniform distribution of data over the scattergram, a simple calculation may aid in the placing of isopleths. On
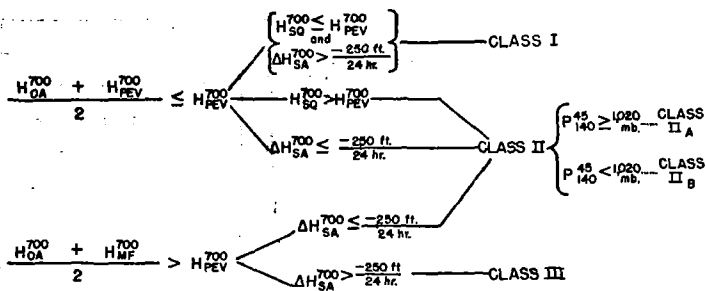
FIGURE 3 (b).—Schematic diagram showing procedure for objective classification of upper-air flow patterns.

the assumption that each line is to be oriented by ten points of rain or no-rain occurrences, the 100-percent line would be located by 10 rain and 0 no-rain points; the 90-percent line by 9 rain and 1 no-rain points; the 80-percent line by 8 rain and 2 no-rain points, etc. Under this supposition, 37 rain cases and 8 no-rain cases, or not quite 5 times as many rain as no-rain cases, should fall above the 60-percent line. Above the 40-percent line, the proportion is 47 to 18. Similar proportions were obtained for other isopleths. However, with the rain and no-rain cases grouped in different portions of the chart, the condition of uniform distribution was not fulfilled. In those scattergrams for which data were insufficient for the accurate drawing of isopleths, the practice was to give them equal spacing. This was true in the spacing of the 0- to 40-percent lines in figure 26 and others.

CLASS I PROCEDURE

The choice and combination of variables for the class I objective procedure were made on the basis discussed in the preceding section, after a consideration of the meteorological conditions associated with this type of upper-air flow. As indicated by the objective classification procedure outlined in figure 3 (b), the pressure distribution aloft during the existence of a class I situation results in the following 700-millibar height relationships.
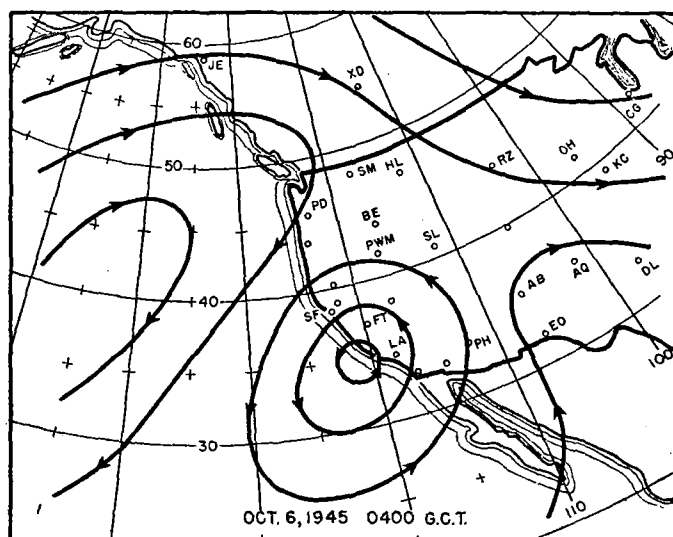
$$\frac{H_{OA}^{700}+H_{MF}^{700}}{2} \leq H_{PEV}^{700}; \qquad H_{SQ}^{700} \leq H_{PEV}^{700};$$
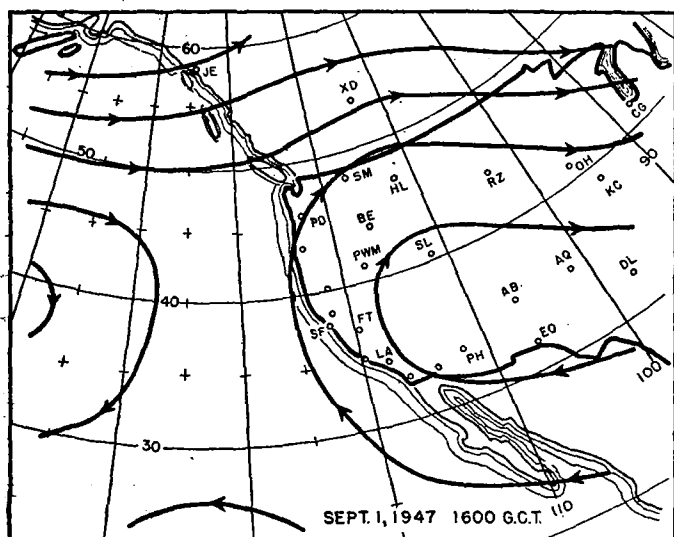
and

$$\Delta H_{SA}^{700} > \left(\frac{-250 \text{ ft.}}{24 \text{ hr.}}\right).$$

METEOROLOGICAL CONDITIONS

The most common type of upper-air flow pattern satisfying the class I criteria is that with the high-level anticyclone well developed and located in its normal position over the United States. As long as this situation prevails, no rain is possible in the area under consideration, due to the warm, dry air aloft in the western portion of the high cell. Under these conditions, temperatures at 700 millibars are generally 10° C. or higher, and the relative humidity above the moist surface layer is less than 20 percent.

The development of the most common type of rain situation in this class results when cyclogenesis occurs aloft or when an upper cold low moves into the area. In the initial stages, cyclogenesis or the movement of an upper low into the area from the south or west is often obscure due to the lack of sufficient upper-air data over Mexico and the Eastern Pacific. The first evidence of the development of a threatening rain situation in this case is noted by an increase in the speed of the winds aloft directly over the valley, with a shift to a southeasterly direction and a gradual drop in the upper-air temperature as the cyclonic circulation intensifies. With continued southerly flow, moisture is gradually brought into the circulation from lower latitudes. When cyclogenesis occurs aloft to the north or northeast, the threat of rain depends on a southward movement of the center. This movement may be followed in the upper circulation.

Still another situation may lead to rain under class I conditions. When the center of the upper-level continental anticyclone is to the south and west of its normal position, conditions become favorable for the movement of tropical storms from low latitudes toward the northwest and into the area just off the west coast of Lower California. When these storms reach a position to the west of the 120th W. meridian and to the north of 25° N. latitude, an influx of very moist tropical air into the forecast area considerably increases the probability of rain. If the tropical storm enters the coast of Lower California, the surface activity will dissipate, but the circulation aloft will continue for some time and may move into the area and cause rain over southern California.

Without regard to the initial stages of development, important amounts of rain will not occur in the forecast area until rather definite conditions of moisture and temperature aloft are attained, with deep cyclonic flow

(a) No-rain situation, with high-level anticyclone well developed and located in normal position over United States.

(b) Well-developed rain situation resulting from cold low aloft.

FIGURE 4.—Maps showing typical circulation patterns at 700-millibar level producing no-rain and rain situations of class I type.

centered just to the southwest of, or over, the area. Typical circulation patterns at the 700-millibar level during no-rain and rain situations in class I are shown in figure 4.

METEOROLOGICAL VARIABLES

Variables chosen for class I were confined to those involving temperature and moisture conditions aloft and the upper circulation. Independent parameters chosen were:

T_{TZM}^{700} Temperature at 700-millibar level at Santa Maria.

T_{MF}^{700} Temperature at 700-millibar level at Medford.

$WD_{MF}^{10,000}$ Wind direction at 10,000 feet at Medford.

$WD_{MF}^{20,000}$ Wind direction at 20,000 feet at Medford.

RH_{ZTM}^{7-500} Average of the raob code figures for the relative humidity at 700-millibar and 500-millibar levels at Santa Maria.

$WD_{DB}^{10,000}$ Wind direction at 10,000 feet at Bakersfield.

These variables were then combined to give a final rainfall parameter, W, as outlined in figure 5.
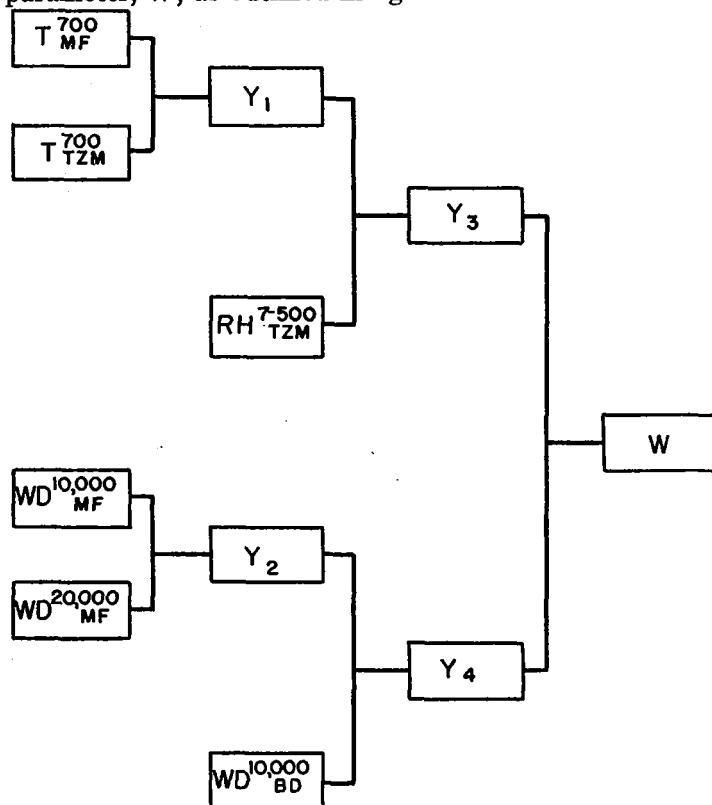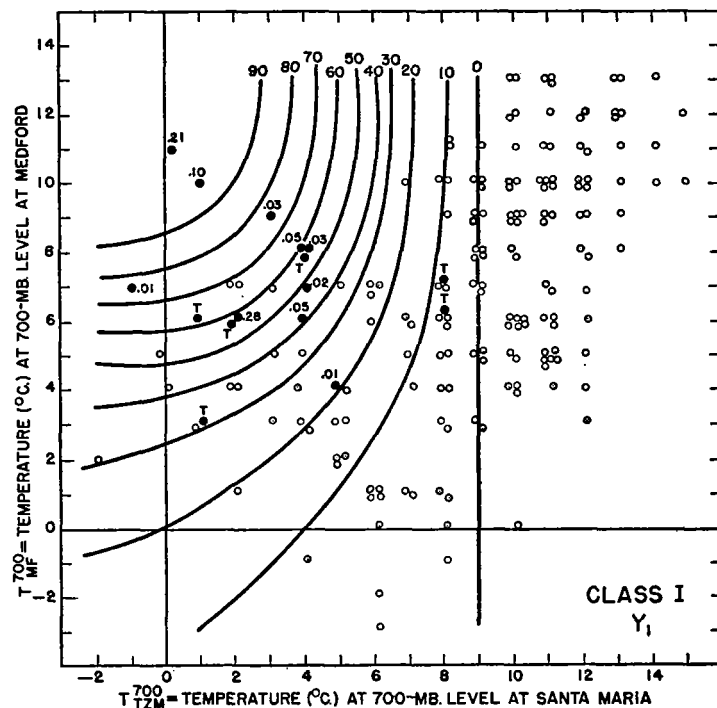
FIGURE 5.—Schematic diagram showing method for combining variables chosen for class I situations into final rainfall parameter, W.

Temperatures at 700 millibars at Santa Maria were plotted as abscissas, and those at Medford as ordinates on a scattergram (fig. 6). Each point was labeled with the amount of precipitation which had occurred during the forecast period (6 to 24 hours after map time). Isopleths were then drawn to the data. Analysis of this graph indicated that in Class I the probability of rain increases with lower temperatures at the 700-millibar level at Santa Maria and higher temperatures at Medford, a distribution of temperature aloft which is a reversal of average conditions and indicates cold air to the south of Medford. If temperatures aloft are sufficiently low at Santa Maria, the center of the cold air is in the vicinity of Santa Maria. The graph shows also that any amount of rain is unlikely with the 700-millibar temperature at Santa Maria higher than 8° C., and important amounts

FIGURE 6.—Graph showing 700-millibar temperatures at Medford plotted against 700-millibar temperatures at Santa Maria, giving isopleths in terms of the dependent variable Y_1. (Values entered beside plotted points indicate recorded precipitation for forecast period.)

unlikely with the temperature above 6° C. The dependent variable read from this graph was labeled Y_1.

Figure 7 is a graph prepared in a similar manner using variables in which the ordinate was the 10,000-foot wind direction and the abscissa was the 20,000-foot wind direction at Medford. As shown by this graph, the probability of rain is greatest with the wind at 10,000 feet from an easterly direction; and at 20,000 feet, from a direction between east and northeast. Interpretation of these facts indicates that for rain to occur in the forecast area,

FIGURE 7.—Graph showing 10,000-foot wind direction at Medford plotted against the 20,000-foot wind direction at Medford, giving isopleths in terms of the dependent variable Y_2. (Values entered beside plotted points indicate recorded amounts of precipitation for forecast period.)

a rather deep layer of cyclonic flow is necessary, with the low pressure center to the south of Medford. In order for rain to be most probable, a slight amount of cold air advection is necessary as indicated by the backing with height. No rain occurred with the 20,000-foot wind from a south-southwest direction through north. The dependent variable taken from this graph was labeled Y_2.

The average raob code figure for relative humidity at the 700-millibar and 500-millibar levels at Santa Maria, which is an indication of the moisture available for the production of rain, was then combined with the dependent variable Y_1, giving the graph of figure 8. This combination gave the dependent variable Y_3, which is a function of the temperature at 700 millibars and the humidity at 700 millibars and 500 millibars. Thus Y_3 represents the temperature and moisture condition of the air mass over the area.
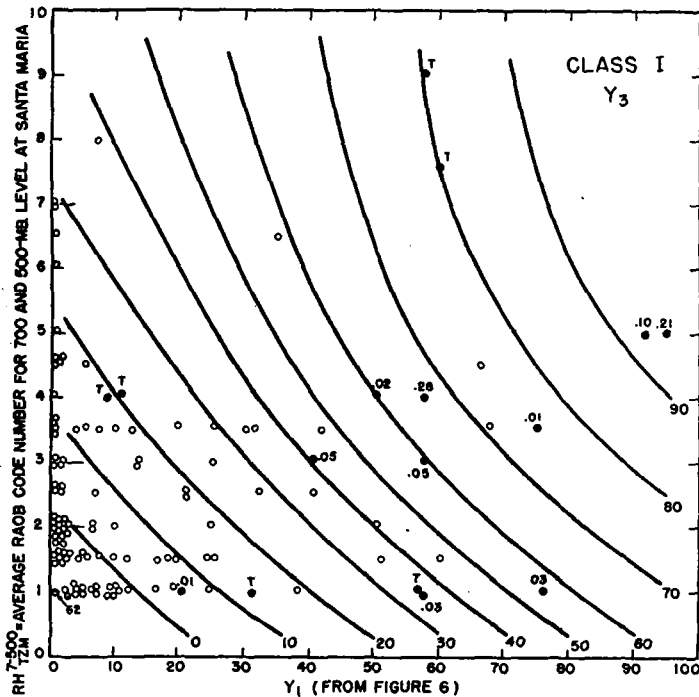

FIGURE 8.—Graph showing values of dependent variable Y_1 plotted against average raob code figure for relative humidity at the 700-millibar and 500-millibar levels at Santa Maria, giving isopleths in terms of the dependent variable Y_3.

In order to localize the center of the cyclonic circulation, indicated as essential in figure 7, the independent variables Y_2 from figure 7 was combined with the wind direction at 10,000 feet at Bakersfield. Results are shown in figure 9. The optimum wind direction at 10,000 feet over Bakersfield for the occurrence of rain is from a northeast to southeast direction, indicating that the closed center must be to the south or southwest of Bakersfield, with the central portion of the San Joaquin Valley in the north or northeast quadrant of the closed low at 10,000 feet. With a shift in the 10,000-foot wind at Bakersfield to a direction with any westerly component, the probability of rain drops off rapidly. The dependent variable Y_4 was taken from the graph of figure 9.

Combination of the variables as outlined in figure 5 was completed when the dependent variables Y_3 and Y_4 were plotted against each other to give the final rainfall parameter W, as shown in figure 10. On this graph, as in the final graphs in the Class II procedure, precipitation amounts occurring during the forecast period were entered above the plotted data and, in order to show the intensity of the storm involved, storm totals were entered in
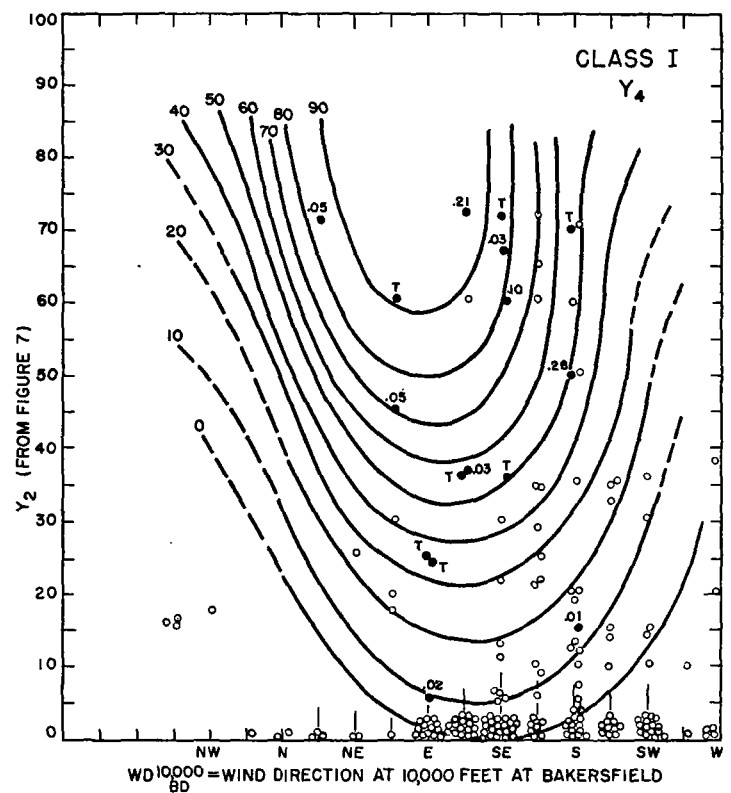

FIGURE 9.—Graph showing values of dependent variable Y_3 plotted against values for wind direction at 10,000 feet at Bakersfield, giving isopleths in terms of the dependent variable Y_4.

brackets beneath the plotted points. In several instances for which the value of W indicated that rain should have fallen, heavy precipitation actually occurred within 12 to 24 hours after the end of the forecast period. This final chart indicates that moderate to high values of both Y_3 and Y_4 are necessary for important amounts of rain to occur.
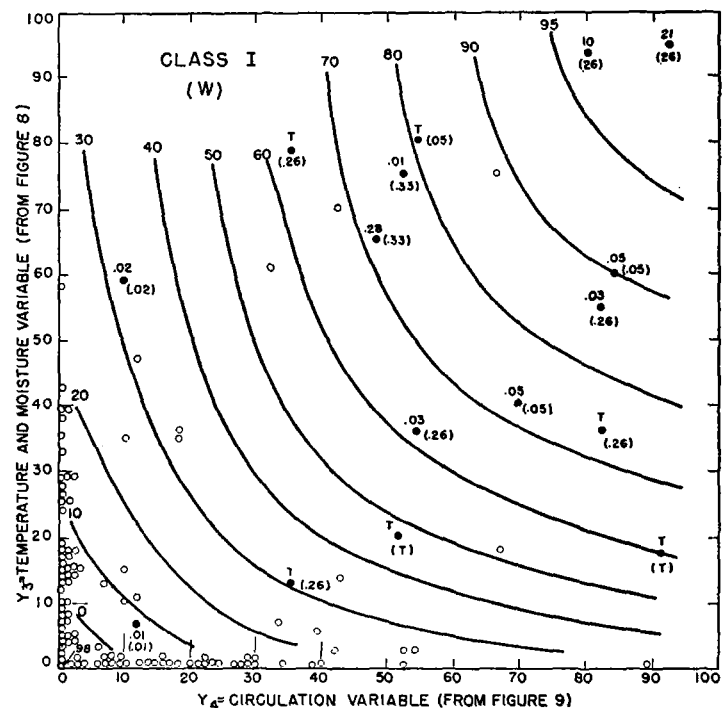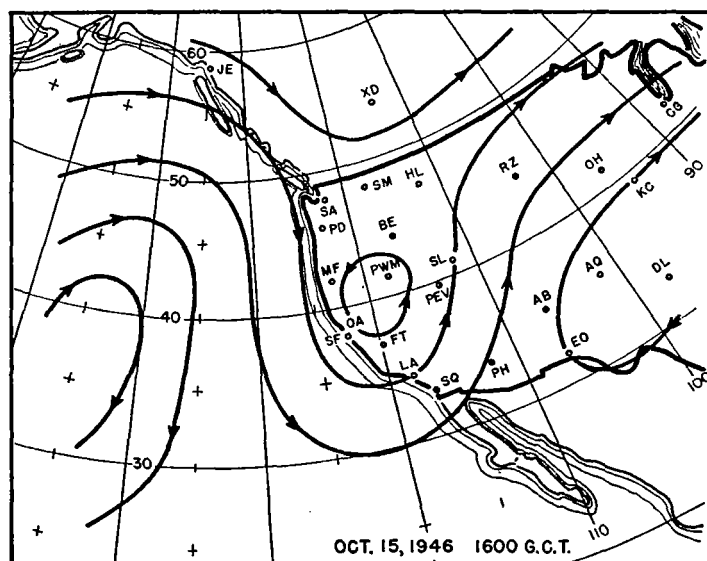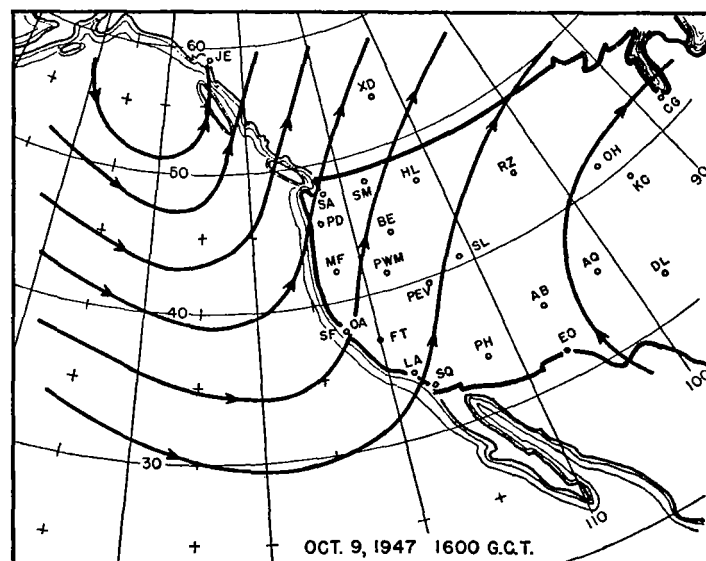

FIGURE 10.—Graph showing dependent variables Y_3 and Y_4 plotted against each other to give the final rainfall parameter W. (Values in brackets are recorded storm totals.)

(a) Class II$_A$.

(b) Class II$_B$.

FIGURE 11.—Maps showing typical circulation patterns at 700-millibar level for rain situations of class II$_A$ and class II$_B$.

CLASS II$_A$ PROCEDURE

As in the development of the Class I procedure, the choice and combination of variables for Class II$_A$ involved a consideration of the meteorological conditions associated with this type of upper-air flow. The classification procedure outlined in figure 3 (b) gave the following objective criteria for defining class II upper-air flow:

$$\frac{H_{OA}^{700}+H_{MF}^{700}}{2} \leqq H_{PEV}^{700}; \qquad H_{SQ}^{700} > H_{PEV}^{700}$$

or

$$\Delta H_{SA}^{700} \leqq \left(\frac{-250 \text{ ft.}}{24 \text{ hr.}}\right).$$

In addition, Class II$_A$ requires that $P_{140}^{45} \geqq 1{,}020$ mb.

METEOROLOGICAL CONDITIONS

When pressures are relatively high at the surface and aloft in the Northeast Pacific, as illustrated in figure 11 (a), the initial stage of the development of a rain situation is the formation in the Pacific Northwest of a relatively small low pressure center with a nearly vertical axis. Colder air is brought into the circulation from the north and northeast. If the coldest air remains over western Washington and the upper circulation increases in intensity, the axis of the low which was originally nearly vertical begins to take on a definite slope, a surface position tending to appear over Nevada and the upper position remaining to the northwest. Surface pressures over Washington and Oregon reflect the upper low pressures, with the result that a surface trough extends toward the northwest from the Nevada low. Large 24-hour pressure falls result from the rapid cyclogenesis over Nevada. However, the formation of an intense low over

Nevada is not sufficient in itself to cause rain in the Valley, although heavy showers may occur over the western slopes of the Sierras. In order for important amounts of rain to occur at lower elevations, there must be, in addition to the plateau low, convergence at higher levels due to the southward movement of the upper closed low. The southward movement is indicated by a sharp drop in temperatures aloft southward along the coast. With the center of the upper low farther to the south, i. e., over northern California, the surface trough becomes less extensive and rainfall becomes more probable. After the cold air has reached into the area, as indicated by a relatively large 24-hour, 700-millibar temperature fall at Santa Maria, rainfall becomes much less probable due to the lack of moisture in the cold air.

METEOROLOGICAL VARIABLES

In order to measure objectively the development of a threatening rain situation of class II$_A$, independent variables were chosen as follows:

T_{MF}^{700}	Temperature at 700-millibar level at Medford.
ΔT_{MF}^{700}	Change in 700-millibar temperature at Medford during past 24 hours.
T_{TZM}^{700}	Temperature at 700-millibar level at Santa Maria.
ΔT_{TZM}^{700}	Change in 700 millibar temperature at Santa Maria during past 24 hours.
$H_{PEV}^{700}-H_{MF}^{700}$	Difference in 700-millibar height at Ely and Medford.
H_{MF}^{700}	Height of 700-millibar level at Medford.
$P_{SA}-P_{TRJ}$	Difference in surface pressure between Seattle and Winnemucca.
ΔP_{TRJ}^{24}	Change in surface pressure at Winnemucca during past 24 hours.

These variables were then combined to give a final rainfall parameter W^A, as outlined in figure 12. The temperature at the 700-millibar level at Medford was first plotted against its 24-hour change (fig. 13). As shown by this chart, the probability of rainfall is higher with a low temperature at Medford and with a large 24-hour fall in temperature. In this subclass where the occurrence of rain is a result of cyclogenesis over the plateau, the low temperature aloft at Medford indicates the availability of sufficiently cold air to initiate the cyclogenesis, while the 24-hour fall in the temperature shows the necessary southward movement of the cold air mass. The dependent variable Z_1^A was obtained from this chart.
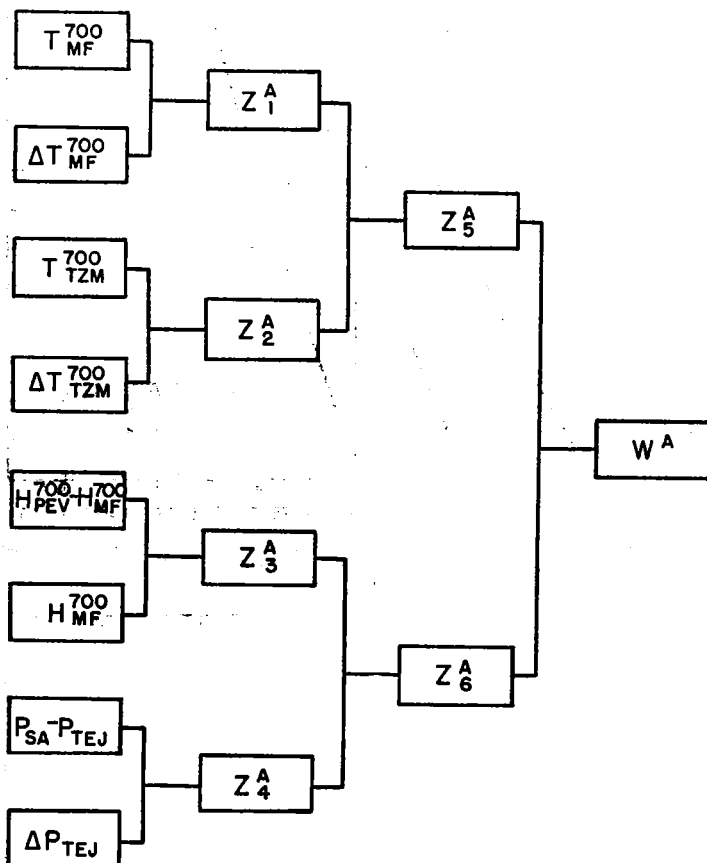

FIGURE 12.—Schematic diagram showing method for combining variables chosen for class II$_A$ situations into final rainfall parameter, W^A.
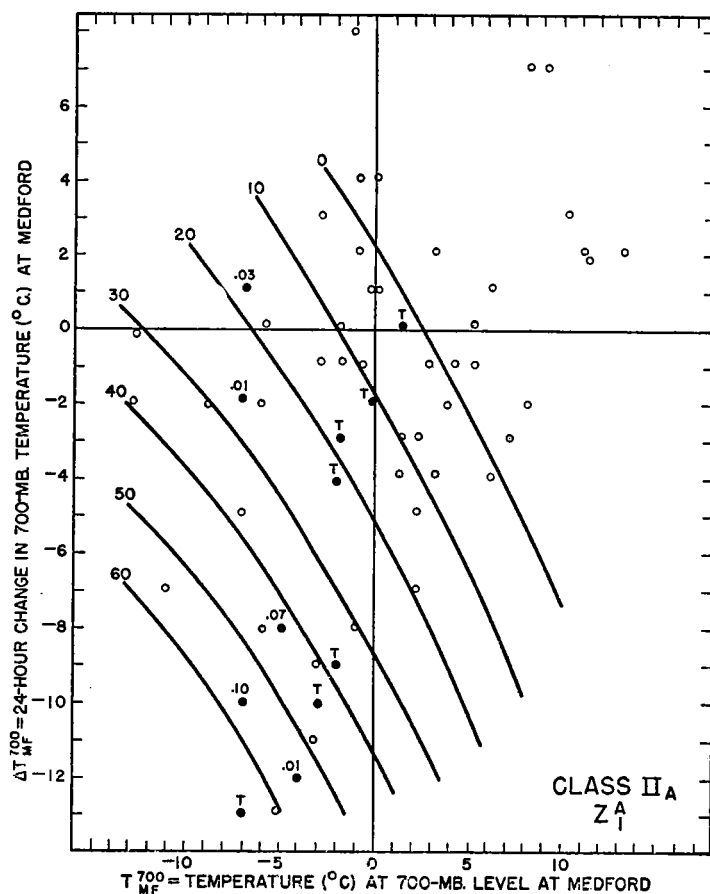

FIGURE 13.—Graph showing temperature at 700-millibar level at Medford plotted against its 24-hour change, giving isopleths in terms of the dependent variable Z_1^A.
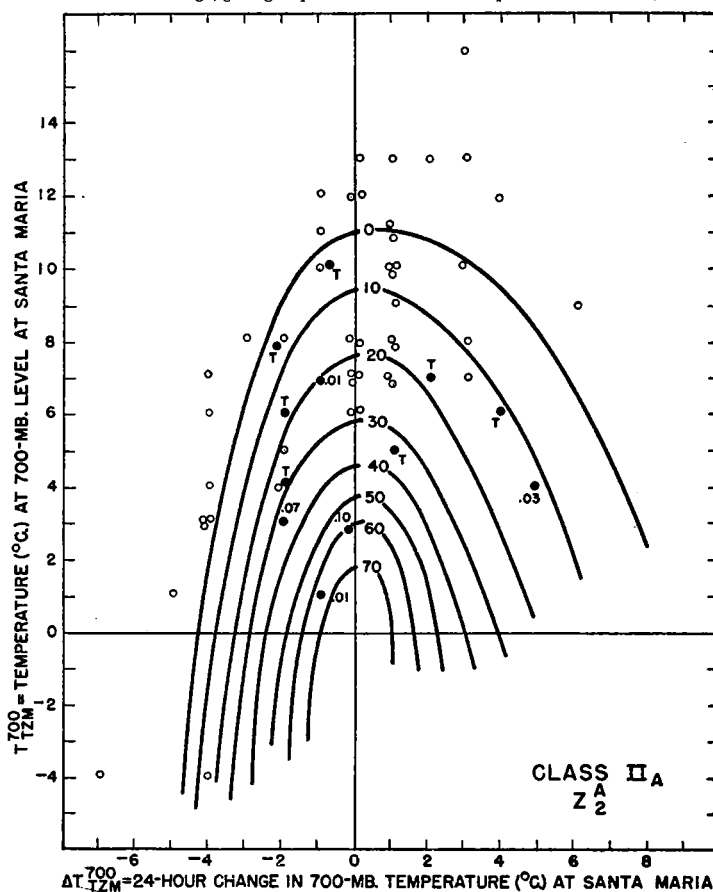
FIGURE 14.—Graph showing temperature at 700-millibar level at Santa Maria plotted against its 24-hour change, giving isopleths in terms of the dependent variable Z_2^A.

The same variables were plotted for Santa Maria (fig. 14), giving the dependent variable Z_2^A. Marked differences can be noted in the distribution of the rainfall occurrence in the two charts, figures 13 and 14. Rainfall is most likely with a 700-millibar temperature at Santa Maria of 0° C. There are indications that a small 24-hour fall in the temperature, ranging from 0° C. to 2° C., gives rise to the highest probability of rain during the following 6- to 24-hour period, while a 24-hour fall in excess of 2° C. indicates a rapid decrease in the likelihood of rain. This relationship may be interpreted as indicating that by the time the cold air has reached as far southward as central California, the influx of air with a lower moisture content—together with a gradual eastward movement of the low pressure system—no longer places the lower elevations of central California in the rain area of the storm.

In order to obtain an indication of the position and intensity of the main trough in the upper circulation, the height of the 700-millibar level at Medford was plotted against the difference in the height of the same variable at Medford and Ely. This graph is shown in figure 15, which indicates that the probability of rain increases with a lower 700-millibar height at Medford and with the height at Ely greater than that at Medford. The threat of rain decreases as the upper low moves eastward with a drop in the 700-millibar level at Ely. The dependent variable read from this chart was $Z_3{}^A$.

The variable of the 24-hour fall in the surface pressure at Winnemucca was plotted (fig. 16) against the difference in the surface pressures at Seattle and Winnemucca. The 24-hour fall in the surface pressure at Winnemucca furnishes an indication of the intensity of the cyclogenesis, while the difference in surface pressure between Winnemucca and Seattle gives indirect information concerning the structure of the upper circulation. With a small difference between the two stations, a position of the upper low center well to the northwest is indicated. With a somewhat higher pressure at Seattle than at Winnemucca, it is more likely that the upper center is nearer the position of the surface low over Nevada. Thus, as indicated by the chart, a definite 24-hour pressure fall at Winnemucca and a considerably higher surface pressure at Seattle than at Winnemucca appear to be required for a threat of rain to develop. The dependent variable $Z_4{}^A$ was obtained from this chart.

In the final combination, the dependent variables $Z_1{}^A$ and $Z_2{}^A$ were plotted against one another (fig. 17), as were

FIGURE 16.—Graph showing the 24-hour fall in surface pressure at Winnemucca plotted against the difference in the surface pressures at Seattle and Winnemucca, giving isopleths in terms of the dependent variable $Z_4{}^A$.
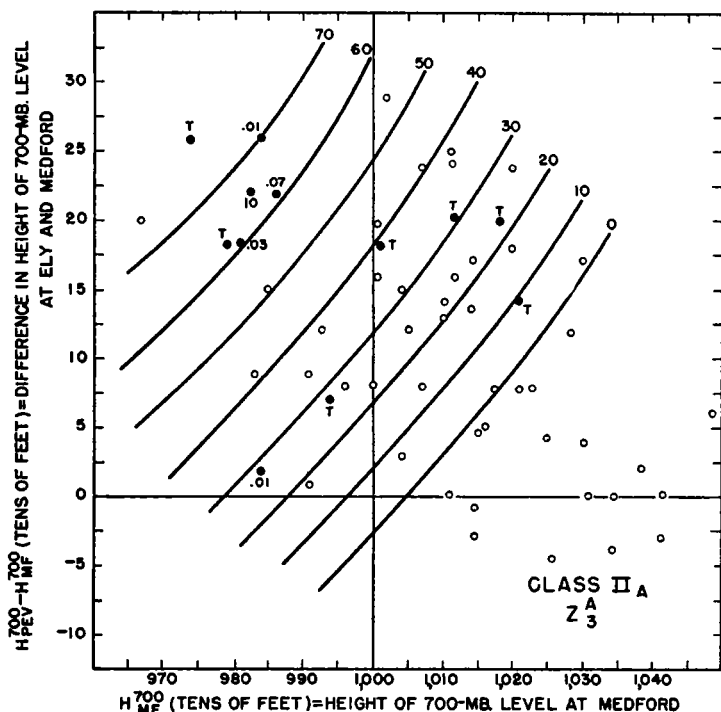

FIGURE 15.—Graph showing the height of the 700-millibar level at Medford plotted against the difference in the height of the same variable at Medford and Ely, giving isopleths in terms of the dependent variable $Z_3{}^A$.
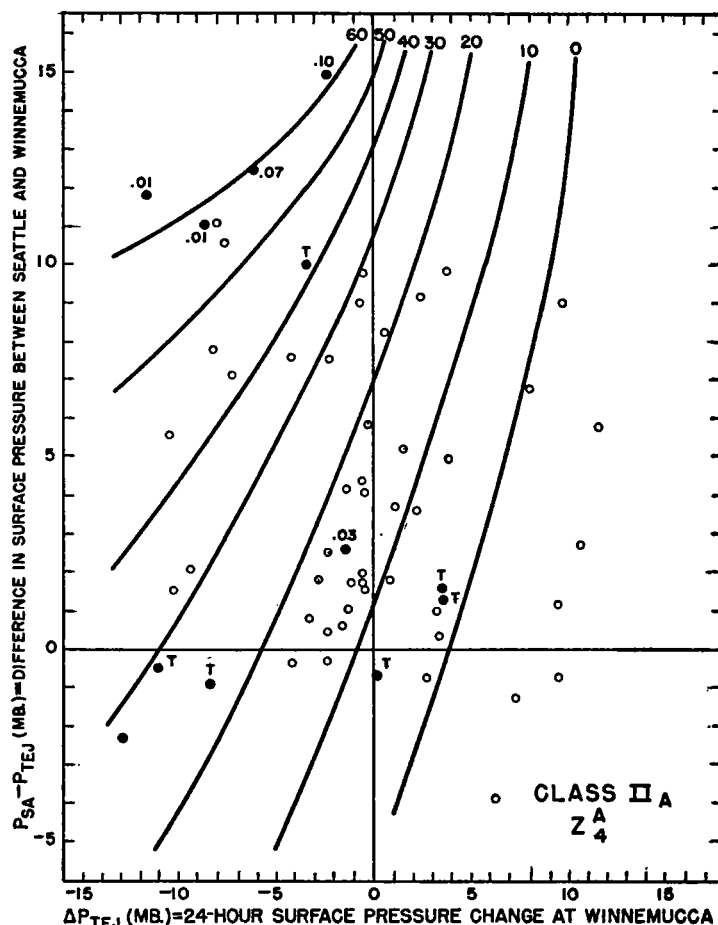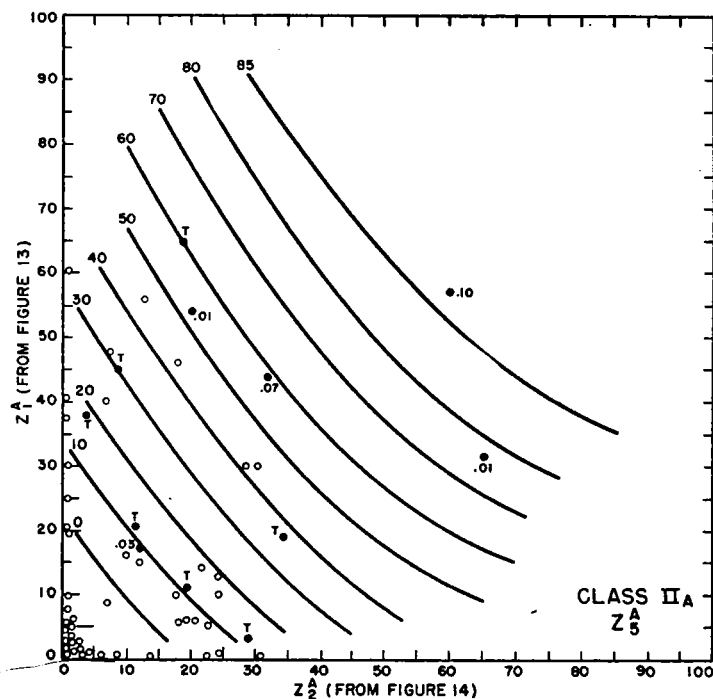

FIGURE 17.—Graph showing dependent variables $Z_1{}^A$ and $Z_3{}^A$ plotted against each other to derive dependent variable $Z_5{}^A$.

variables $Z_3{}^A$ and $Z_4{}^A$ (fig. 18). Results from each of these graphs were dependent variables $Z_5{}^A$ and $Z_6{}^A$, respectively, and they were in turn combined (fig. 19) to give a final rainfall parameter $W.^A$

CLASS II$_B$ PROCEDURE

The development of class II$_B$ procedure involved the same type of consideration found useful in classes I and II$_A$. Again, a study of meteorological conditions associated with the upper-air flow was made. The objective criteria defining class II$_B$ upper-air flow were the
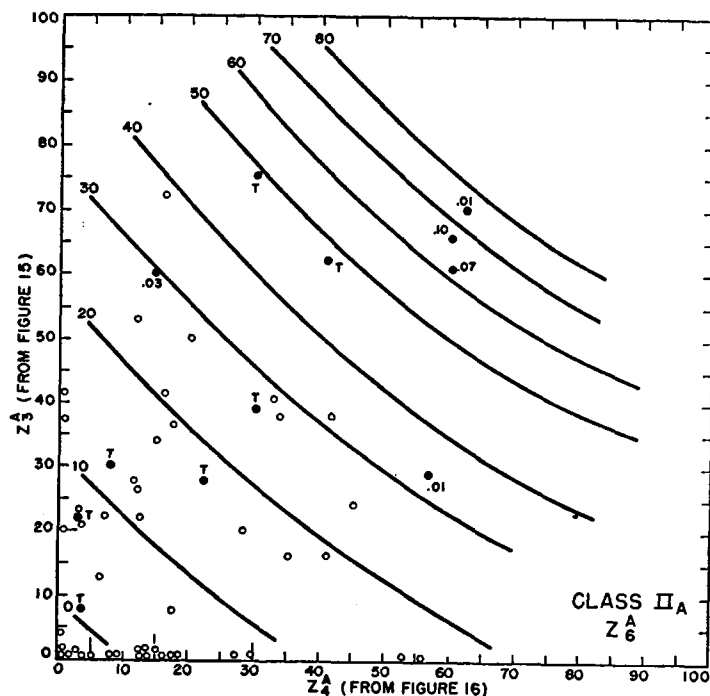
same as for class II$_A$, except that class II$_B$ required, according to figure 3 (b) that

$$P_{140}^{45} < 1,020 \text{ millibars}$$

METEOROLOGICAL CONDITIONS

As illustrated in figure 11 (b), the main feature of the upper circulation for class II$_B$ is a broad trough off the Pacific coast. The anticyclonic centers over the continent and over the Northeast Pacific are very weak. These centers also are displaced southward and eastward in the case of the continental cell, and southward and westward in the case of the Pacific cell.

During the existence of this type of upper-air flow, fronts approach the Pacific coast from a southwest through a northwest direction. Near the coast, the fronts are retarded as they move into the eastern portion of the stationary upper trough, and conditions become favorable for the development of unstable waves on the frontal systems. If a wave development occurs as far south as about 40° N. latitude, and within several hundred miles of the coast, conditions are favorable for rain to spread inland into northern and central California and as far south as Fresno.

With the development of a frontal wave just off the coast, the pressure at Eureka falls rapidly. Figure 20 indicates that a wave development of sufficient intensity to cause the Eureka pressure to drop below about 1,015 millibars brings a threat of rain to central California. Therefore, the combination of surface pressure at Eureka with the height of the 700-millibar level at Medford (fig. 20) gave a powerful graph for use in forecasting rain in the central San Joaquin Valley. On this graph a line was drawn separating the rain and no-rain cases, with two no-rain cases appearing in the rain portion, and three traces of rain appearing in the no-rain portion. However, the graph failed to give worthwhile quantitative results, and its use in the study was limited to a determination of whether or not rain would occur and, therefore, whether a consideration of other variables would be necessary.

FIGURE 18.—Graph showing dependent variables $Z_3{}^A$ and $Z_4{}^A$ plotted against each other to derive dependent variables $Z_5{}^A$.
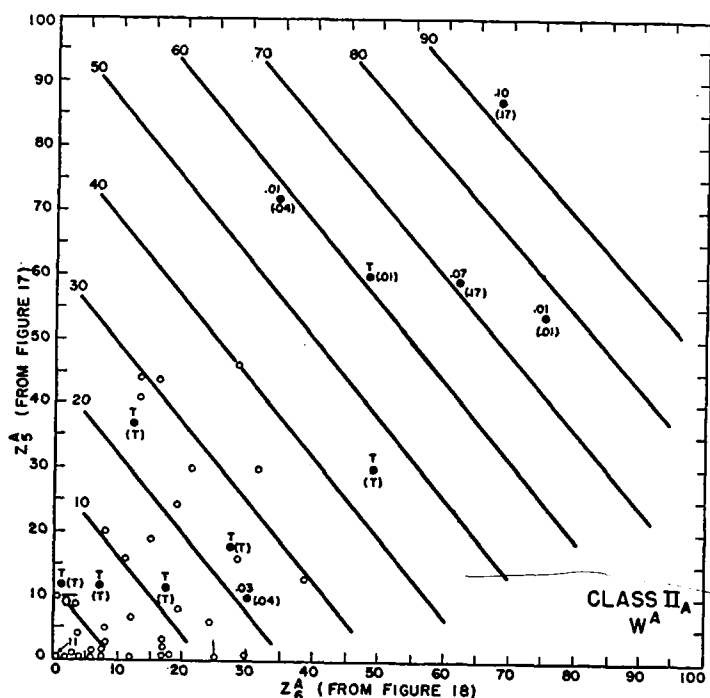

FIGURE 19.—Graph showing dependent variables $Z_5{}^A$ and $Z_4{}^A$ plotted against each other to give the final rainfall parameter W^A.
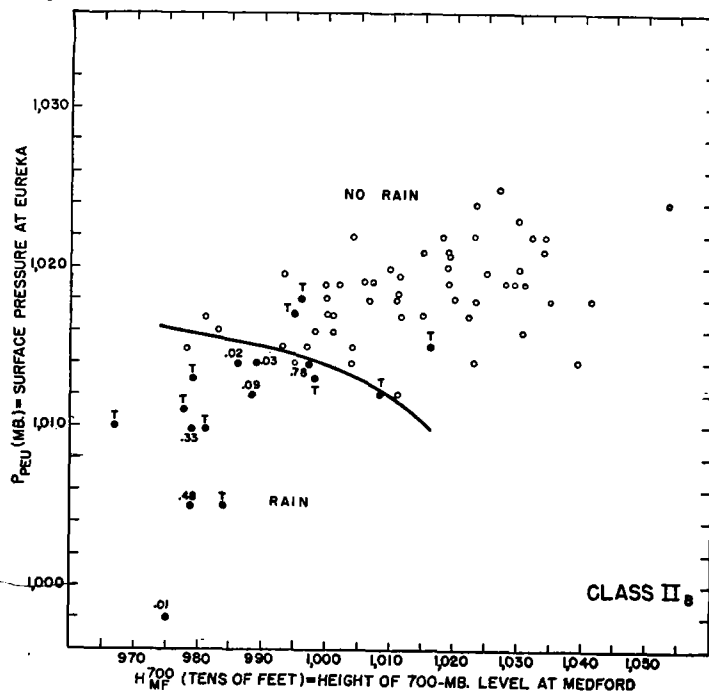

FIGURE 20.—Graph showing the surface pressure at Eureka plotted against the height of the 700-millibar level at Medford, for forecasting rain occurrence in class II$_B$ situations.

The wave developments during class II_B conditions appear to have the ability to "carry" sufficient moisture along with the disturbance to cause heavy rain over a wide area, even though the air mass a short distance in front of the system is relatively dry. However, if moist tropical air has been bought into the circulation prior to the wave development and remains in the area, the convergence associated with the deepening wave may cause heavy showers several hundred miles ahead of the front.

METEOROLOGICAL VARIABLES

From the above considerations the following independent variables were chosen:

T_{TZM}^{700} — Temperature at 700-millibar level at Santa Maria.

ΔT_{TZM}^{700} — Change in 700 millibar temperature at Santa Maria during past 24 hours.

DP_{TZB} — Surface dew point at Sandberg.

H_{MF}^{700} — Height of 700-millibar level at Medford.

$H_{PEV}^{700} - H_{MF}^{700}$ — Difference in height at 700-millibar level between Ely and Medford.

P_{PEU} — Surface pressure at Eureka.

$P_{PEU} - P_{PD}$ — Difference in surface pressure between Eureka and Portland.

These seven variables were then combined to give a final rainfall parameter, W^B, as outlined in figure 21. First, figures 22 and 23 were plotted, using the same variables as those used in figures 14 and 15, respectively, in the treatment of class II_A situations. In figure 22, as compared with figure 14, a somewhat greater 24-hour fall in the temperature at the 700-millibar level at Santa Maria is associated with a rain situation, but only a slight differ-

FIGURE 22.—Graph showing temperature at 700-millibar level at Santa Maria plotted against its 24-hour change, giving isopleths in terms of the dependent variable $Z_1{}^B$.

ence is noted in the existing temperature. A comparison of figure 23 with figure 15 indicates a great similarity, with the main difference being noted in the better segregation of the no-rain cases in the lower right-hand portion of figure 23. Although the development of typical rain situations in the two subclasses shows major differences as to origin and growth, the upper-air characteristics are similar to the extent indicated by a comparison of the corresponding charts.
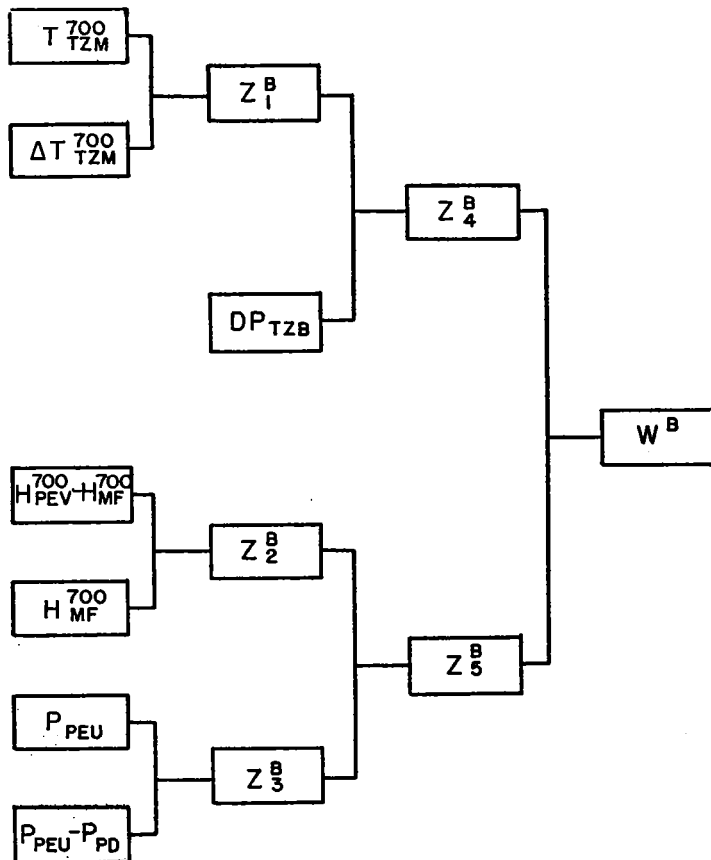

FIGURE 21.—Schematic diagram showing method for combining variables chosen for class II_B situations into final rainfall parameter W^B.

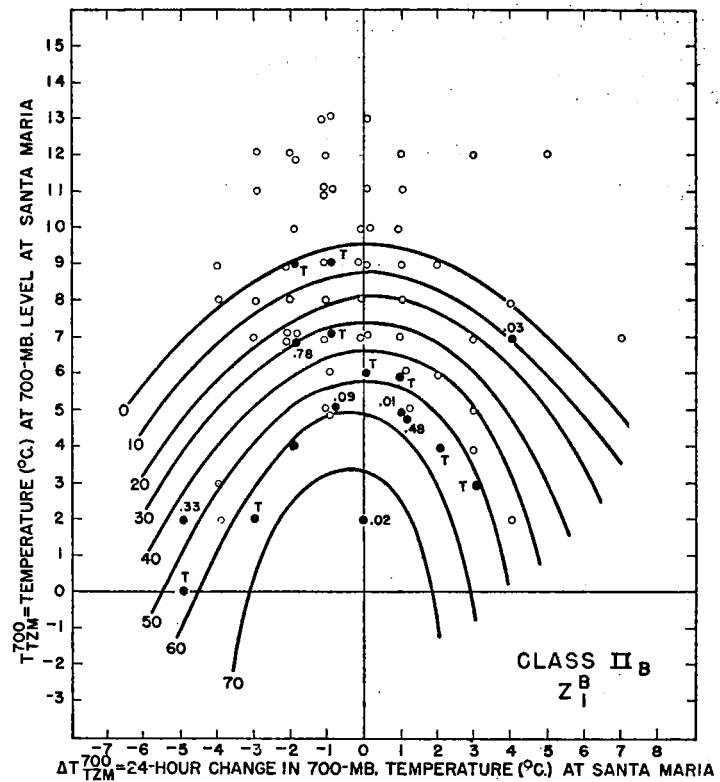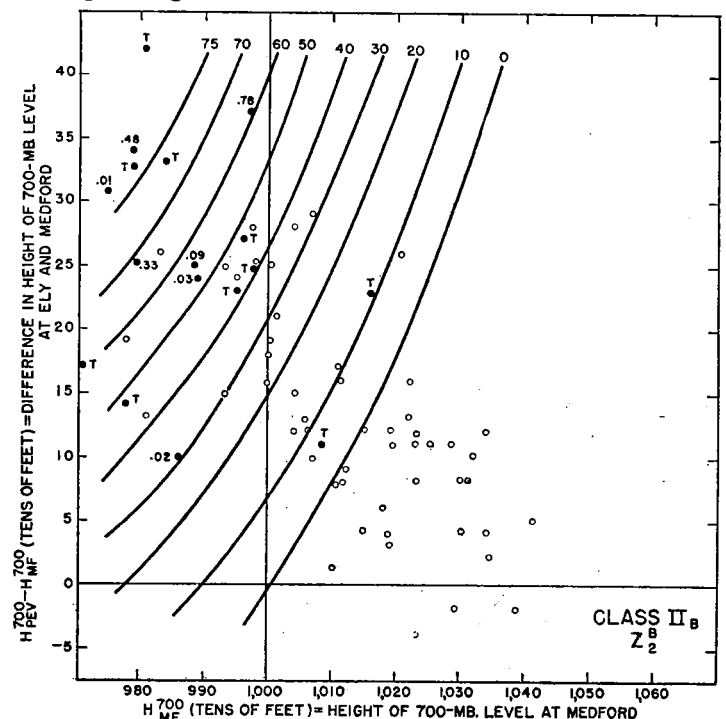FIGURE 23.—Graph showing the height of the 700-millibar level at Medford plotted against the difference in the height of the same variable at Medford and Ely, giving isopleths in terms of the dependent variable $Z_4{}^B$.

Much better stratification of rainfall data than that already found in figure 20 was obtained by pairing the surface pressure at Eureka with a second variable indicating the location of the lowest pressure along the coast relative to Eureka and Portland. The pressure at Eureka was combined with the difference in pressure between Eureka and Portland, as shown in figure 24. As indicated by this chart, the probability of important amounts of rain becomes greater with a low pressure at Eureka and with a value near or lower than at Portland.

As a means of detecting the type of situation in which abnormally moist air invades the area prior to the wave development, the dew point at Sandberg, located in the Tehachapi mountains just to the south of the San Joaquin Valley at an elevation of 4,517 feet, was combined with the dependent variable $Z_1{}^B$. Results are shown in figure 25, in which the data indicate a higher probability of rain with the higher dew points.

The dependent variables were then combined to give the final parameter W^B, as shown in figures 26 and 27.
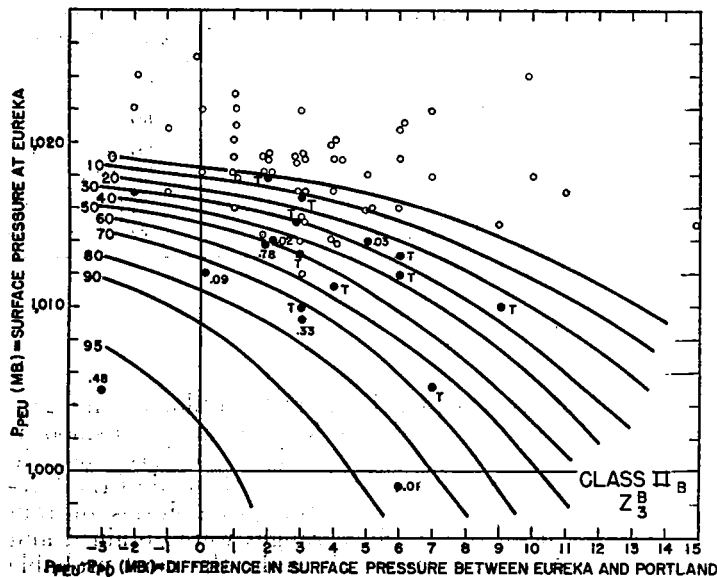
FIGURE 24.—Graph showing the surface pressure at Eureka plotted against the difference in surface pressures between Eureka and Portland, giving isopleths in terms of the dependent variable $Z_1{}^B$.
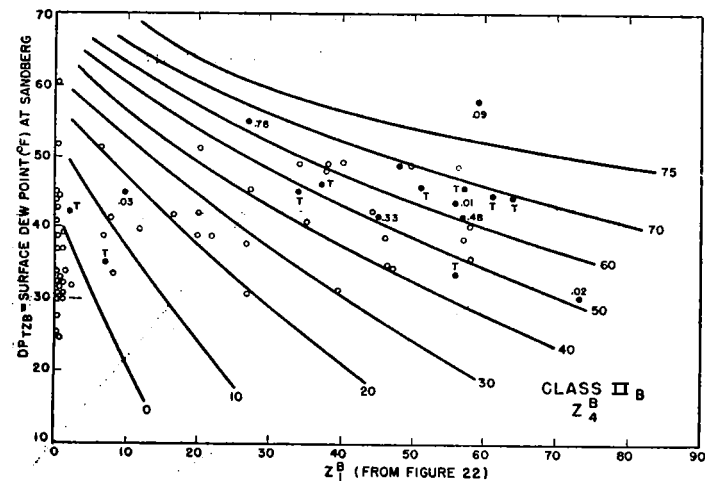
FIGURE 25.—Graph showing the surface dew point at Sandberg plotted against dependent variable $Z_1{}^B$, giving isopleths in terms of the dependent variable $Z_4{}^B$.
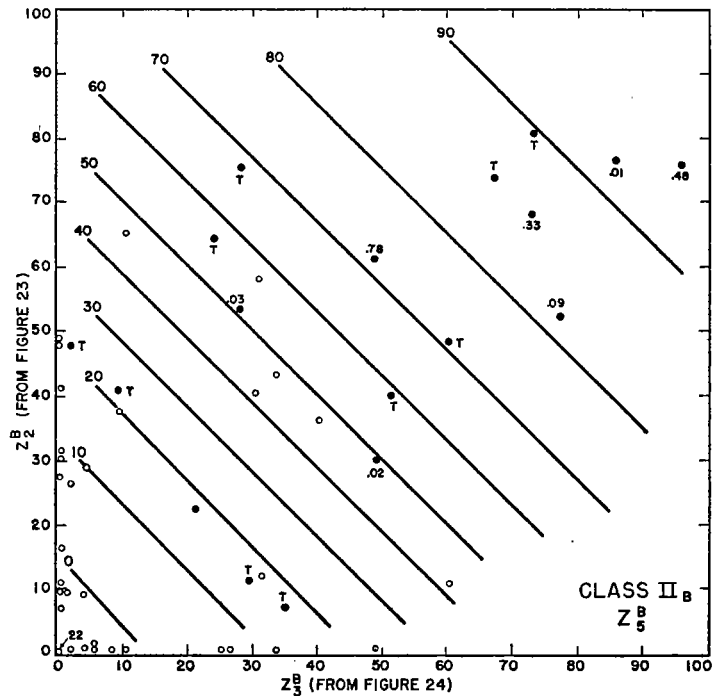
FIGURE 26.—Graph showing dependent variables $Z_3{}^B$ and $Z_4{}^B$ plotted against each other to derive the dependent variable $Z_5{}^B$.
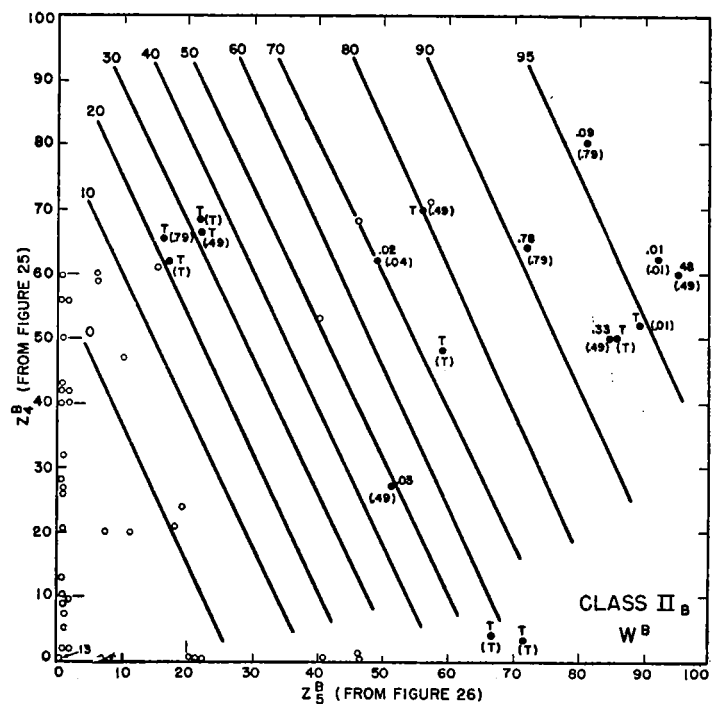
FIGURE 27.—Graph showing dependent variables $Z_4{}^B$ and $Z_4{}^B$ plotted against each other to give the final rainfall parameter W^B.

CLASS III PROCEDURE

No rain occurred during the existence of a class III situation in the period of the study. Therefore, it was unnecessary to develop the objective procedure beyond the objective classification step. However, as a longer period of record becomes available, it is quite probable that an especially prolonged period of showers during a change into class III or a rapid change from class III to class I may result in rain occurrence within 6 to 24 hours of a class III type of upper-air flow. For that reason it is well to keep in mind the principal features of the upper-air flow associated with those changes. The procedure outlined in figure 3 (b) indicates the following objective criteria for defining class III upper-air flow:

$$\frac{H_{OA}^{700}+H_{MF}^{700}}{2}>H_{PEV}^{700}$$

and

$$\Delta H_{SA}^{700}>\left(\frac{-250\ \text{ft.}}{24\ \text{hr.}}\right)$$

A rain situation usually is terminated with the movement eastward of the cyclonic circulation aloft, consisting of a cold low of class I or a trough common to class II. As a result of this eastward movement of the upper-air systems, the winds aloft along the Pacific Coast shift into a northerly direction, with the pressure distribution aloft satisfying the criteria set up for class III. Although this class is quite often a transitional stage between class I and class II, with a relatively short duration, it may persist for a considerable period if the high pressure ridge aloft is of sufficient intensity.

APPLICATION OF THE CHARTS

In the preparation of the various charts, any quantity of rainfall, including a trace, was used to indicate a rain situation for all classes and subclasses. This quantitative agreement made possible a combined summarization of the W values derived for the three classes. Although some variation is indicated in the final accuracy of the forecasting charts for the various classes and subclasses, differences are not sufficiently well-defined to justify individual treatment. Class I situations, the predominant type, prevailed 44 percent of the time; class II situations prevailed 26 percent of the time, with nearly equal division between occurrences of each subclass; and class III situations prevailed the remaining 30 percent of the period of study.

RELATION OF W TO PRECIPITATION AMOUNTS

Although W was defined for the purpose of estimating the probability of rain, it was studied further as an indicator of rainfall amounts. In order to obtain a relationship between W and the occurrence of various rain amounts during a period 6 to 24 hours after forecast time, the number of occurrences of various values of W within specified ranges of precipitation was tabulated by employing the graphs in figures 10, 19, and 27. The results of the tabulation are shown in table 1. In designating these ranges, amounts of 0.04 inch or more were combined into one range of precipitation, inasmuch as it was considered probable that when the 6 rainfall stations averaged as much as 0.04 inch of rain, some areas would record damaging amounts of precipitation. From table 1, cumulative percentage frequencies of the various W values within specified limits of precipitation amounts were derived (shown in table 2).

Tᴀʙʟᴇ 1.—*Tabulation of the number of occurrences of various W values within specified ranges of precipitation*

W	Precipitation amounts (inches)		
	0	T-0.03	0.04 or more
0-10	390	3	0
11-20	30	2	0
21-30	14	5	0
31-40	7	4	0
41-50	0	1	0
51-60	3	3	0
61-70	3	5	0
71-80	0	6	3
81-90	2	3	1
91-100	0	3	7

Tᴀʙʟᴇ 2.—*Cumulative percentage frequencies of the various W values within specified ranges of precipitation (computed from table 1)*

W	Precipitation amounts (inches)		
	0	T-0.03	0.04 or more
0-10	99	100	
11-20	94	100	
21-30	74	100	
31-40	64	100	
41-50	0	100	
51-60	50	100	
61-70	38	100	
71-80	0	67	100
81-90	33	83	100
91-100	0	30	100

The cumulative frequencies were then plotted (fig. 28), and smoothed lines were drawn for the data. In smoothing the lines, consideration was given to those cases in which rain occurred a short time after the end of the forecast period. From figure 28, the probabilities of rain occurrence within the specified ranges were obtained and recorded in table 3. From this table, the most probable rainfall amount, depending on the value of W would be:

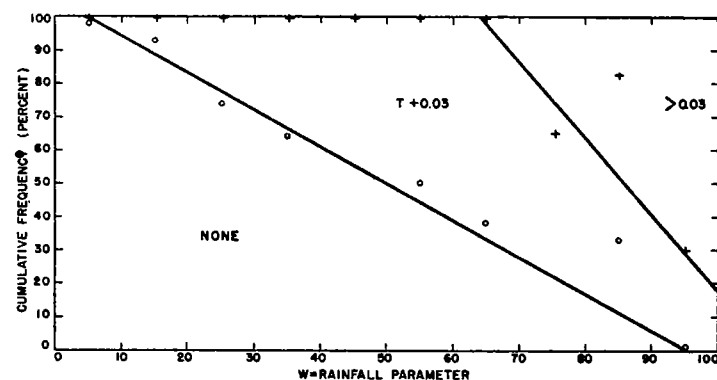| w	Amount
0-49	0
50-81	T-0.03 inch
82-100	0.04 inch or more

Fɪɢᴜʀᴇ 28.—Graph showing relationship between values of rainfall parameter W and the cumulative frequencies of occurrence of various rain amounts during a period 6 to 24 hours after forecast time. (See table 2.)

TABLE 3.—*Relation between W and the probability that the rain amount will fall within a specified range*

W	0	T-0.03	0.04 or more	W	0	T-0.03	0.04 or more
1	100			51	49	51	
2	100			52	47	53	
3	100			53	46	54	
4	100			54	45	55	
5	100			55	44	56	
6	99	1		56	43	57	
7	97	3		57	42	58	
8	96	4		58	41	59	
9	95	5		59	40	60	
10	94	6		60	39	61	
11	93	7		61	37	63	
12	92	8		62	36	64	
13	91	9		63	35	65	
14	90	10		64	34	66	
15	89	11		65	33	65	2
16	88	12		66	32	64	4
17	86	14		67	31	62	7
18	85	15		68	30	61	9
19	84	16		69	29	60	11
20	83	17		70	28	58	14
21	82	18		71	26	58	16
22	81	19		72	25	57	18
23	80	20		73	24	56	20
24	79	21		74	23	54	23
25	78	22		75	22	53	25
26	77	23		76	21	52	27
27	75	25		77	20	50	30
28	74	26		78	18	50	32
29	73	27		79	17	49	34
30	72	28		80	16	47	37
31	71	29		81	15	46	39
32	70	30		82	14	43	43
33	68	32		83	13	43	44
34	67	33		84	12	42	46
35	66	34		85	11	41	48
36	65	35		86	10	40	50
37	64	36		87	8	39	53
38	63	37		88	7	38	55
39	62	38		89	6	37	57
40	61	39		90	5	35	60
41	60	40		91	4	34	62
42	59	41		92	3	33	64
43	57	43		93	2	31	67
44	56	44		94	1	30	69
45	55	45		95	0	29	71
46	54	46		96		27	73
47	53	47		97		24	76
48	52	48		98		22	78
49	51	49		99		20	80
50	50	50		100		17	83

TABLE 4.—*Forecast verification of original data*

OBSERVED (inches)	FORECAST (inches)			Total
	0	T to 0.03	0.04 or more	
0	441	6	2	449
T to 0.03	15	15	5	35
0.04 or more	0	3	8	11
Total	456	24	15	495

USE OF METHOD DURING THE 1947 SEASON [3]

Prior to the beginning of the 1947 season, this study had been tentatively completed and in this form it was used during the fruit drying season. Its contribution to the forecasts issued for the raisin-growing area was considerable, although the actual value was difficult to estimate. The use of the method to show the limiting of the possibility of rain for apparently threatening situations proved to be of almost as much value as its use for forecasting rain. For reasons explained earlier, a correct forecast of no rain during a threatening situation is of as much value to the fruit growers as a correct rain forecast.

At the end of the 1947 season, the possible addition of another year's record to the short period available, together with the insight gained from another season's use, indicated the advisability of the inclusion of the 1947 data in the final results. A slight change was made in the objective criteria differentiating between class I and class II, but no revision was made in class III.

However, it was found that in class II, a division of the class into two subtypes to distinguish between a westerly or northerly approach of a front was essential. This division had been anticipated earlier in the study but had not been carried out because of lack of data. Accordingly, the revision was made and incorporated into the method. As a result of the revision, the use of several additional independent variables was found to be worthwhile. In the summarization of the forecasts for the 1947 season (table 5), the revised values of W and of the objective forecast when changed by the completed study have been entered in parentheses to the right of the values obtained before revision.

CONCLUSIONS

1. The development of an objective forecasting method such as described in this report appears to rest on (a) a division of map types into meteorologically sound classifications, and (b) a choice of independent variables suitable to each classification.

2. Whether the objective method developed is used in whole or in part, the relationships shown between the different variables are of considerable value to the forecaster in the forecasting occurrence of rain or in the limiting of the amount of rain to be expected.

3. Independent data are not available for satisfactory tests of the method other than that already indicated for the 1947 season. Until such tests become possible, the use of the method must be restricted to support of general forecasting procedures.

4. With the accumulation of more cases, further refinements will become worth while. The number of cases in

FORECASTING SKILL OF METHOD

Applied to the original data, forecasts based on these ranges in W gave the results shown in the contingency table, table 4.

The standard skill score testing procedure [2] which was applied to the original data resulted in a value of 70 percent on a rain (T or more) or no-rain basis, and a value of 61 percent on the basis of the rainfall amount occurring in the correct range. Through a separation of the qualitative and quantitative aspects of the forecasting problem, considerable improvement probably could be effected in the quantitative value of the forecasting method.

[2] The skill score, S_e, in this study is defined by

$$S_e = \frac{C - E_e}{T - E_e}$$

where C=number of correct forecasts, E_e=number of forecasts expected to be correct due to chance, and T=total number of forecasts.

It has a value of unity when all forecasts are correct, and zero when the number of correct forecasts is equal to the number expected to be correct due to chance. The value of E_e for forecasts of "rain" or "no rain" is given by

$$E_e = R \times f_r + N(1 - f_r)$$

where R=forecast number of rain cases during the period covered by forecasts; N=forecast number of no-rain cases during period covered by forecasts and f_r=relative frequency of occurrence of rain cases during the period covered by forecasts. (From Table 4: $C=472$; $T=495$; $R=39$; $f_r=\frac{46}{495}$; $N=456$; $(1-f_r)=\frac{449}{495}$; $S_e=.70$.)

The value of E_e on the basis of forecasts for the rainfall amounts in the specified ranges is given by

$$E_e = R_1 \times f_1 + R_2 \times f_2 + N(1 - f_1 - f_2)$$

where R_1=forecast number of rain cases falling in the range T to 0.03 inch during the period covered by forecasts; R_2=forecast number of rain cases falling in the range 0.04 inch or more during the period covered by forecasts; N=forecast number of no-rain cases during the period covered by forecasts; f_1=relative frequency of occurrence of rain cases in the range T to 0.03 inch during the period covered by forecasts; and f_2=relative frequency of occurrence of rain cases in the range 0.04 or more during the period covered by the forecasts. (From Table 4: $C=464$; $T=495$; $R_1=24$; $f_1=\frac{35}{495}$; $R_2=15$; $f_2=\frac{11}{495}$; $N=456$; $1-f_1-f_2=\frac{449}{495}$; $S_e=.61$.)

[3] Although complete verification data are not available for the 1948 raisin-drying season, the author has indicated that the method again gave good results. A skill score of .62 based on climatology derived from the study, was attained during the season.—*Editor.*

TABLE 5.—*Summary of objective and actual precipitation forecasts for the 1947 season and their verifications*

Date	Class	W	10:30 a. m. objective forecast	Actual forecast	Observed weather	Class	W	10:30 p. m. objective forecast	Actual forecast	Observed weather
September 1947										
1	I	0	NR	NR	NR	I	5	NR	NR	NR
2	I	0	NR	NR	NR	IIA	0 (0)	NR	NR	NR
3	I	0	NR	NR	NR	IIA	0 (0)	NR	NR	NR
4	I	0	NR	NR	NR	I	0	NR	NR	NR
5	I	0	NR	NR	NR	IIB	0 (0)	NR	NR	NR
6	IIB	8 (0)	NR	NR	NR	IIB	42 (0)	NR	Few spkls or very lgt shwrs	NR
7	IIB	31 (0)	NR	NR	NR	IIB	23 (0)	NR	NR	NR
8	IIB	10 (0)	NR	NR	NR	III	0	NR	NR	NR
9	IIA	31 (2)	NR	NR	NR	III	0	NR	NR	NR
10	III	0	NR	NR	NR	III	0	NR	NR	NR
11	I	0	NR	NR	NR	I	0	NR	NR	NR
12	III	0	NR	NR	NR	III	0	NR	NR	NR
13	III	0	NR	NR	NR	III	0	NR	NR	NR
14	I	0	NR	NR	NR	I	0	NR	NR	NR
15	I	0	NR	NR	NR	I	0	NR	NR	NR
16	IIA	13 (6)	NR	Few spkls	NR	IIA	95 (77)	>.03(T-.03)	Ocnl lgt shwrs.	.01
17	IIA	95 (61)	>.03(T-.03)	NR	T	IIA	33 (0)	NR	NR	NR
18	IIA	12 (6)	NR	NR	NR	IIA	3 (0)	NR	NR	NR
19	I	0	NR	NR	NR	I	10	NR	NR	T
20	I	25	NR	NR (Few lgt shwrs next day)*	NR	I	59	T-.03	NR	NR
21	I	23	NR	Threat of rain remaining.	T	I	56	T-.03	Few lgt shwrs	NR
22	I	32	NR	NR	NR	I	0	NR	NR	NR
23	I	0	NR	NR	NR	I	0	NR	NR	NR
24	I	0	NR	NR	NR	I	0	NR	NR	NR
25	I	0	NR	NR	NR	IIB	0 (0)	NR	NR	NR
26	IIB	0 (0)	NR	NR	NR	I	0	NR	NR	NR
27	I	0	NR	NR	NR	I	0	NR	NR	NR
28	I	0	NR	NR	NR	IIB	10 (0)	NR	NR	NR
29	I	0	NR	NR	NR	I	0	NR	NR	NR
30	I	0	NR	NR	NR	IIB	10 (0)	NR	NR	NR
October 1947										
1	IIB	23 (0)	NR	NR	NR	IIB	9 (0)	NR	NR	NR
2	IIB	10 (0)	NR	NR	NR	III	0	NR	NR	NR
3	III	0	NR	NR	NR	I	0	NR	NR	NR
4	I	18	NR	NR	NR	IIA	16 (22)	NR	NR	NR
5	I	0	NR	NR	NR	IIB	61 (3)	T-.03(NR)	NR	NR
6	IIB	52 (51)	T-.03	NR	NR	IIB	43 (74)	NR(T-.03)	Few spkls north ptn	T
7	IIB	78 (94)	T-.03(>.03)	Few spkls	T	IIB	61 (70)	T-.03	Very lgt rain north ptn next day	NR
8	IIB	43 (33)	NR	NR	T	IIB	13 (50)	NR(T-.03)	Few spkls north Ft	.03
9	IIB	55 (97)	T-.03(>.03)	Rain tonight	.48	IIB	39 (93)	NR(>.03)	Few shwrs this mrng	.33
10	IIB	42 (80)	NR(T-.03)	Sctd lgt shwrs tonight	T	IIB	37 (19)	NR	Few shwrs	NR
11	III	0	NR	NR	NR	III	0	NR	NR	NR
12	III	0	NR	NR	NR	III	0	NR	Sctd lgt shwrs Ft. south	NR
13	III	0	NR	NR	NR	III	0	NR	NR	NR
14	IIB	38 (0)	NR	NR	NR	IIB	42 (5)	NR	Lgt rain north of Ft. late tonight	NR
15	IIB	75 (93)	T-.03(>.03)	Mdt to hvy rain late tonight and next day.	T	IIB	62 (96)	T-.03(>.03)	Itmt rain Ft. north by aftn and over vly tonight and next day.	.01

*On Sept. 20, the warning direct to growers stated "scattered light showers late tonight, with possibly heavier showers tomorrow." This warning resulted in the stacking or rolling of about 50 percent of the exposed raisin crop.

class II is limited by the fact that it is more of a winter situation, occurring generally later in the season. With further cases of cyclogenesis off the coast, the quantitative aspects of class IIB may be improved.

5. In developing the method, the selection and combination of the variables was determined by occurrence of rain rather than by the amounts of rain. Some improvement may be gained by incorporating the rain amounts in the selection and treatment of the independent variables.

ACKNOWLEDGMENTS

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